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Particulate Control Highlights

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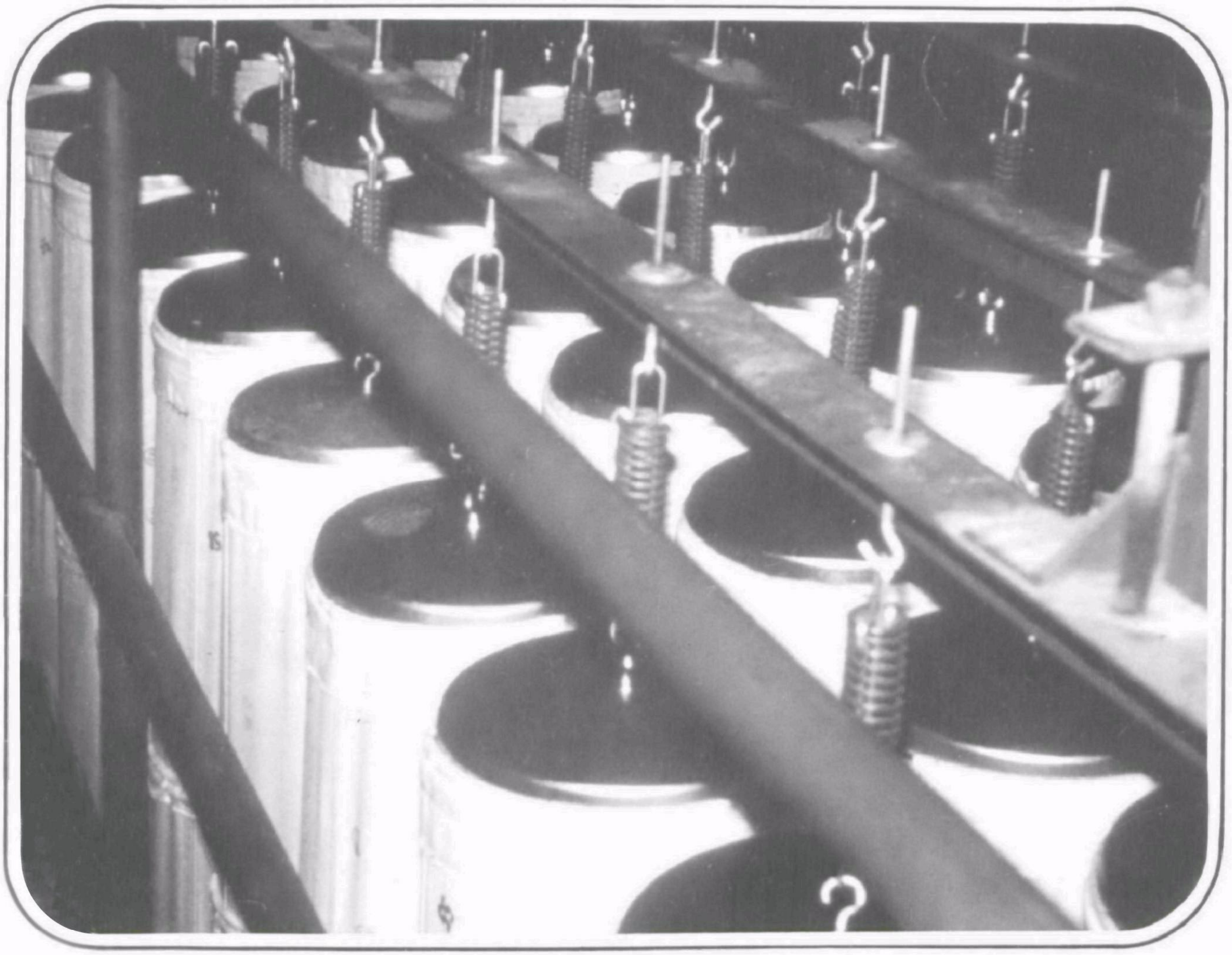
Research on Fabric Filtration Technology



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Particulate Control Highlights: Research on Fabric Filtration Technology

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ABSTRACT

Significant developments in fabric filtration technology are highlighted in this report. Selected results of several field and laboratory studies performed over the last 10 years by or under the sponsorship of the U.S. Environmental Protection Agency are reviewed so that the user may better assess the capabilities and limitations of filtration equipment. Discussions are initiated with a background presentation of fabric filter design and operational concepts followed by a sampling of actual field performance with various coal fly ash aerosols and a description of an operational, mobile pilot filter system that is used to facilitate the selection of operating parameters, fabric type and method of fabric cleaning. Fabric weave and constitutents are discussed with respect to their bearing on working temperatures, method of cleaning, fabric life, pressure loss and dust retention properties. Attention is also called to pinhole or pore leakage and its impact upon collection efficiency and effluent size properties. The pros and cons of increasing air-to-cloth ratio (face velocities) to reduce fabric and other capital costs are compared with the attendant disadvantages of increased power needs and higher emission rates. Both pilot and bench scale tests show that effluent concentrations increase very rapidly with face velocity. Recently developed modeling concepts that provide realistic predictions of glass fiber performance with coal fly ash are reviewed.

CONTENTS

FIGURES

TABLES

SECTION 1

RESEARCH ON FABRIC FILTRATION TECHNOLOGY

BACKGROUND

A rigorous state-of-the-art appraisal of air and gas cleaning technology was initiated by the U.S. Environmental Protection Agency in 1969. As part of the overall program, GCA/Technology Division undertook a fabric filter systems study that culminated in the preparation of a Handbook of Fabric Filter Technology, and equally important, in the identification of future research needs. Since 1969, several laboratory and field studies have been performed by GCA in which the theoretical and applied aspects of filtration have been examined. Considerable effort has been directed towards the control of fly ash emissions from stationary sources. This area becomes increasingly important with increased coal combustion and stricter particulate emission regulations. Despite the considerable historical background, critical data necessary for the optimum use of filtration technology were not available in 1969. The research projects summarized in this report represent part of an ongoing effort to fill in these gaps.

The control of fly ash emissions from coal-fired boilers has until recently fallen within the domain of electrostatic precipitators (ESP). Prior to the development of high temperature glass fabrics, precipitators and scrubbers afforded the only practical means for hot gas cleaning. Consequently, with the successful evolution of the latter technologies there was little incentive to experiment with untested fabric filters even with the advent of special, high temperature fabrics. The picture has changed, however, since the promulgation of the 1971 New Source Performance Standards (NSPS) by the U.S. Environmental Protection Agency. A review of experience at many coal-fired steam-electric generators has revealed that the NSPS of 43 ng/Joule* is not attained by existing ESP systems. Several possible reasons for noncompliance have been discussed in a recent EPA report[1] along with suggested corrective measures. High ash electrical resistivity, which reduces ESP particle capture, is a major problem that will become more severe as the need to burn low sulfur coal increases. Therefore, the role of fabric filtration as a practical control alternative has been carefully studied.

With respect to SO_2 removal, wet (alkaline) scrubbing now affords a viable approach. In most applications, however, precollection of particulates by ESP or fabric filters is prerequisite to effective utilization of absorbing liquids and to compliance with particulate emission standards. Limited field applications and recent laboratory research suggest that fabric filtration will eventually play a larger role in the control of coal fly ash emissions.

THE FILTRATION PROCESS

Fabric filters, as a class, provide the highest collection efficiencies of all particulate control devices at the expense of a significant operating pressure drop, ~0.50 to 1.75 kPa† relative to ~0.1 kPa for an ESP and 3 to 10 kPa for low to high energy wet scrubbers. When allowance is made for total energy usage and capital cost factors, however, annualized costs for fabric filters and electrostatic precipitators are much closer than suggested by their respective operating pressure drops. Those fabrics designed for hot gas filtration usually display emission rates less than one tenth of those for an ESP system with comparable inlet loadings. At ambient temperatures, emissions can be reduced by up to two orders of magnitude by using woven napped fabrics. The term "nap" refers to a mechanically induced, loose fiber cover on the fabric surface that greatly enhances filter performance.

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*43 ng/Joule = 0.1 lb/10^6 Btu.

†1 kPa = 4 in. water.

The predominant particle capture mechanism at high loadings, >0.5 g/m^3, is *sieving* by the dust layer that builds up on the fabric surface.[2,3] Only during the first few minutes of filtration with new or just cleaned fabrics, do the classical collection mechanisms prevail; i.e., inertial impaction, diffusion and interception with or without augmentation by secondary processes. An ideal filter should function as a supporting substrate for the dust layer which, without discontinuities in the form of cracks or pinholes, constitutes a nearly impenetrable layer for particles of the same size making up the dust cake. Unfortunately, normal variations in fabric structure such as nonuniform pore size or an absence of free fibers within the pores may lead to significant dust penetration. *Only when the fabric pores (interyarn openings) are spanned by an intercepting fiber array is it possible to obtain complete pore bridging and hence a solid dust cake as shown in Figure 1.*

High interstitial fiber counts are associated with many fabrics woven from staple yarns (cotton and numerous synthetics), especially those that are napped. Because staple yarns are spun from short, ~5 to 10 cm long fibers, many fibers project from the yarns, thus providing extended collection surface. When both warp and fill yarns are spun from staple fibers, the discrete fiber fraction far exceeds that afforded by the mix of staple and multifilament yarns customarily found in glass fabrics. Warp yarns; i.e., those that extend lengthwise in a loom, are usually aligned with the bag axis. The crossing yarns are described as fill or woof yarns. Unfortunately, most nonmineral fibers will fail at flue gas temperatures because of physical and chemical degradation.

However, twill-weave glass fabrics with special surface lubricants to reduce yarn abrasion have been used successfully in the U.S.A.[3,4,5] The axially-aligned warp yarns, which are spun from continuous filaments, provide the tensile strength whereas the bulked fill yarns furnish the extended fiber surface needed for particle capture. Unfortunately, complete pore bridging may not be obtained such that some of the approaching aerosol escapes. *Thus, with glass fabrics, collection may be reduced to the 99.9 percent range in contrast to the 99.999+ levels attainable at ambient temperatures with napped and/or all staple fabrics.*

Dust concentration; particle size, shape and charge; and humidity influence fabric pressure drop through their effects on the characterizing specific resistance coefficient, K_2, for the dust* and dust cake release during cleaning.[2] Increased filtration velocity or air-to-cloth ratio leads to increased filter resistance and outlet concentration. *Hence, for a given system, velocities must not exceed some limiting value when using this approach to reduce fabric and space requirements.*[2,3]

A typical filter system, Figure 2, consists of many vertically aligned bags or tubes suspended in several compartments through which the gas flow is uniformly distributed. Compartments are sequentially isolated from the system by control valves to allow cleaning and maintenance without system shutdown. Uniformity in operating pressure drop and emissions increase with the number of compartments. With too few compartments, excessive differences in pressure loss may cause flow fluctuations which would be unacceptable for most combustion and ventilation processes.

Glass fabrics used for fly ash filtration are usually cleaned by bag collapse and reverse flow with occasional augmentation by *gentle* mechanical shaking. Conversely, vegetable and organic fiber fabrics can withstand vigorous shaking or, in the case of felted media, high energy pulse jet action. The latter process in-

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*K_2 is the proportionality constant in the equation which states that the increase in pressure loss, P, across the filter is proportional to the filtration velocity, V, and the change in the areal density of the dust deposit, W; i.e., $P = K_2VW$.

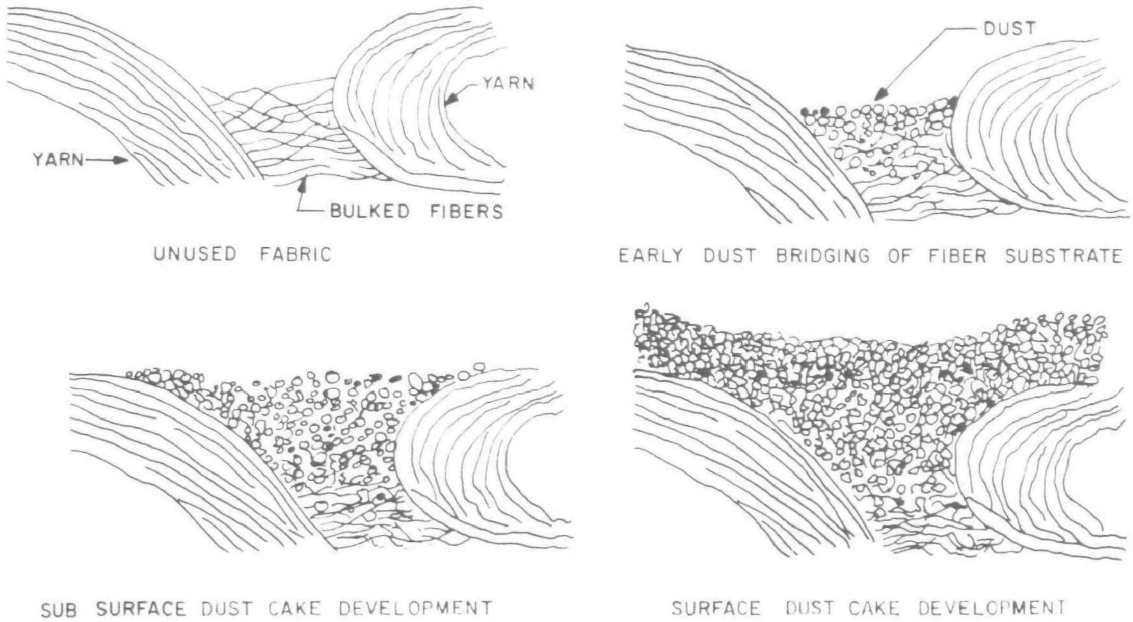


Figure 1. Schematic, dust accumulation on woven glass fabrics.

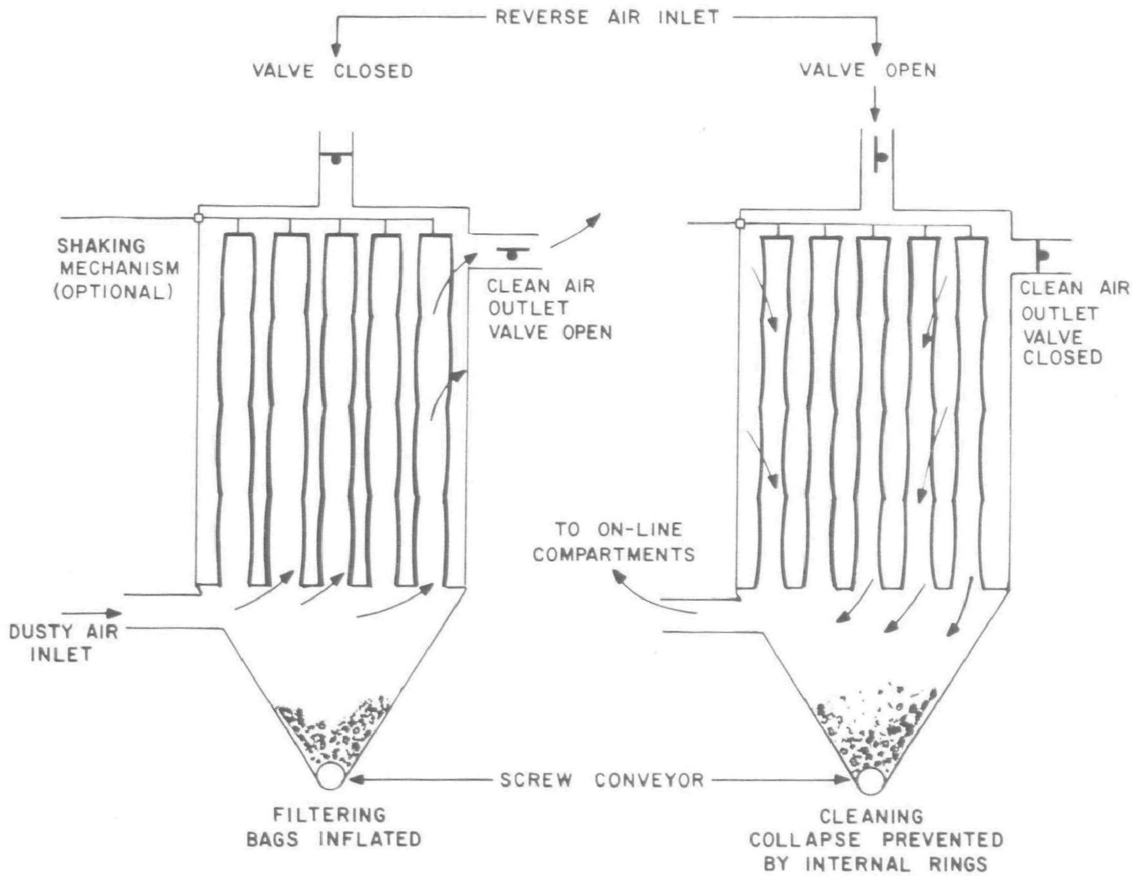


Figure 2. Schematic, single compartment operation in a multicompartment filter system.

volves the discharge of brief, ~0.1 sec, pulses of compressed air at about 90 psig (0.622 MPa) into the bag outlet. The resulting rapid flexing of the bag dislodges the surface dust layer. Except for pulse jet systems, the isolation time for compartment cleaning varies from 2 to 5 minutes including at least 1 minute with no cleaning action so that dust may settle to the hopper.

In contrast to electrostatic precipitators, the efficiency of fabric filters is expected to be independent of the electrical resistivity of the ash. There are potential problems, however, to be avoided. For example, failure to maintain gas temperature above its dewpoint can lead to condensation related difficulties; i.e., excessive pressure drop requiring (a) boiler turndown unless a bypass capability is provided and (b) possible rupture of filter bags. Remedial measures used or proposed to prevent condensation include complete system insulation supplemented by internal heaters and continuous gas recirculation during shutdown.[2,3]

Interstitial penetration of tar droplets and fine particles during the break-in of new bags must also be minimized. Injection of fly ash, limestone or other mineral dusts during boiler startup and preheating periods will precoat fabrics sufficiently to provide a cleanable, superficial deposit.

Although no major difficulties are foreseen, boiler scale-up from 50 to 500 MW or greater may reveal some unanticipated problems. It should be noted that reported bag lives of up to 4½ years are not based upon the burning of typical pulverized coal.[5] *On-line testing of new, fabric filter controlled, coal-fired systems now under construction will answer these questions.* Several research programs designed to improve the quality of filtration are reviewed in the next section.

FIELD PERFORMANCE MEASUREMENTS

Field measurements have been conducted[4-6] to evaluate woven, glass fabrics used to control dust emissions from coal-fired boilers and steel-producing arc furnaces. Systems were tested at the Sunbury Plant of the Pennsylvania Power and Light Company[5] using a fuel mixture of anthracite and petroleum coke in 43 MW pulverized fuel boilers and at the Nucla Plant of the Colorado Ute Electric Association[4] where a bituminous coal was burned in 13 MW, spreader stoker units. Similar evaluations were carried out on fabric filters used to contain emissions from 30-ton, electric arc furnaces at the Marathon LeTourneau Company in Longview, Texas.[5]

Standard EPA sampling methods were used to estimate mass concentrations and particle size properties. Based upon 31 tests at the Sunbury facility,[5] the average mass emission rate was 1.98 ng/J of coal fired which corresponds to an average weight collection efficiency of 99.91 percent. Similarly, 22 tests at the Nucla Plant indicated an average mass emission rate of 4.3 ng/J, equivalent to a collection efficiency of 99.84 percent.[6] Currently, 43 ng/J is the allowable (NSPS)* emission rate for fossil fuel-fired steam generators. No significant deviations from the average emission rate were noted for variations in firing rate, fuel sulfur content, or fuel ash content.

Cascade impactors were used to determine particle size properties up- and downstream of the filters. These tests were supplemented by condensation nuclei measurements so that the fine particles in the effluent could be better characterized. According to Sunbury tests, there was no significant reduction in aerodynamic mass median diameter, aMMD ~7.5 μm, as the fly ash passed through the filter. On the other hand, an apparent decrease, 6.5 to 5.5 μm, aMMD was observed at the Nucla installation. Subsequent laboratory tests indicated that dust samples collected immediately before and after the above fabrics showed no significant size differences.[3] The Nucla size reduction was attributed to an appreciable loss of the larger particles, >15 μm diameters, between the upstream sampling point and the filter face by gravity and inertial separation. *The similarity of up- and downstream size properties is explained by the fact that 95 percent or more of the downstream aerosol is composed of the upstream aerosol fraction that*

*NSPS - New Source Performance Standards for Particulate Emissions from Coal-Fired Boilers with Firing Rate in Excess of 74.8 x 10^6 MJ/sec. Promulgated by U.S. Environmental Protection Agency. December 1971.

has passed unchanged through pinholes or unblocked pores.

The disadvantage with field tests is that operating conditions cannot be readily varied nor can special measurements be carried out except at prohibitive costs. On the other hand, the importance of field tests, when supported by laboratory measurements, cannot be overstated.

The application of glass fabric filters at high temperatures was also evaluated for electric furnace operations. Limited measurements indicated emissions in the range of 0.0032 to 0.0044 g/m^3, well below the allowable EPA limit of 0.012 g/m^3.

DESIGN AND FIELD EVALUATION OF A MOBILE FABRIC FILTER SYSTEM

The high efficiencies for fabric filters and the prospect of stricter regulations have accelerated filtration research. A major advantage of laboratory experiments is that the experimenter can custom-design his system so that selected parameters can be varied at will. Draemel,[8] has related the performance of 123 fabrics to clean fabric and test dust parameters. However, a notable disadvantage of most laboratory investigations is that the simulated aerosol seldom duplicates the field aerosol.

While field studies eliminate the problem of aerosol simulation, it is rarely possible to alter cleaning parameters, substitute different fabrics, vary face velocities or institute other field changes. As a means of providing versatility while simultaneously working with real aerosols, the Environmental Protection Agency contracted with GCA/Technology Division to design, fabricate and evaluate a mobile fabric filter system.[9] *By extracting a representative fraction of an industrial gas stream as the test aerosol, a practical means is provided to evaluate fabrics, cleaning methods and filter operating modes on a pilot scale.*

The EPA mobile fabric filter system has the following capabilities:

- Filtration can be conducted at cloth velocities as high as 6.1 m/min at pressure differentials up to 5 kPa and gas temperatures up to 290°C.
- The system can be cleaned by mechanical shaking, pulse jet or low pressure reverse flow with the capability to vary the frequency and intensity of cleaning.
- The unit can be operated as a single or three-compartment system with automatic controls to facilitate long term testing.

Design and performance features for the system are described in a report prepared for the U.S. Environmental Protection Agency.[9] Field tests were conducted at a secondary bronze smelter, a hot mix asphalt plant and a coal-fired, power station to appraise the system's capability. At the conclusion of a successful evaluation period, the mobile system was delivered to the Environmental Protection Agency for subsequent use in a large scale program in which a mobile wet scrubber and electrostatic precipitator were also included.

FABRIC STRUCTURE AND FILTER PERFORMANCE

The most efficient woven fabrics are those whose yarns are spun from staple fibers where many free fibers occupy the pore region. When these fibers with diameters ranging from ~5 to 30 μm are uniformly dispersed, they provide an effective substrate for dust layer growth (Figure 1).

Yarns spun solely from glass staple are characteristically low in tensile strength.[3] Therefore, compromise weaves with multifilament warp (axially aligned) yarns are used to provide the necessary tensile strength. Unfortunately, this approach diminishes the quantity of discrete fiber collectors that enhance filter performance.

Microscopic observation of fabrics furnishes valuable insights on probable field performance.[3] In conjunction with thread counts, weave type and yarn dimensions, one can estimate the number and size of the pores which may vary appreciably from one fabric to another.[3] However, the number of open pores may be drastically reduced (~50 percent) with some fabrics due to yarn proximity, thus decreasing permeability.

Although contributing significantly to tensile strength, multifilament yarns are poor particle collectors. Hence, a nonuniform distribution or absence of intrapore fibers can cause pinhole leaks shown in Figure 3. In Figure 3a, the pinhole, whose dimensions were defined roughly by the 100 μm yarn spacing, appeared in a 3/1 twill weave glass fabric. Figure 3b shows a monofilament screen with 200 μm openings in which bridging is only 95 percent complete.

Once filter resistance increases to 0.75 kPa or greater, a few pinholes can lead to excessive dust penetration because their low resistance to air flow leads to pore velocities 1000 times or more greater than the average face velocity. *Thus, even if the total pinhole area in only 0.01 percent of the total filter area, 10 to 20 percent of the total flow may pass through the pores.* With respect to Figure 3b, more than 98 percent of the flow channeled through the 5 percent pinhole area.[3]

Clean cloth permeability may be a poor index of particle collection because resistance alone may not reflect the presence of substrate fibers nor the number and size distribution of the pores. In addition to direct microscopic observations, simple tests with submicrometer dusts provide excellent insights as to dust capture potential. A modest improvement in efficiency with atmospheric dust, 64 versus 40 percent for cotton and glass fabrics, respectively, may signal a dramatic lowering in fly ash outlet concentration; e.g., from 10^{-3} to 10^{-5} g/m^3.[3]

Because temporarily or permanently unblocked pores are characteristically associated with many fabrics including the glass media used for fly ash collection,[5,6] it is important to note the effect of these pore properties on filter effluents.

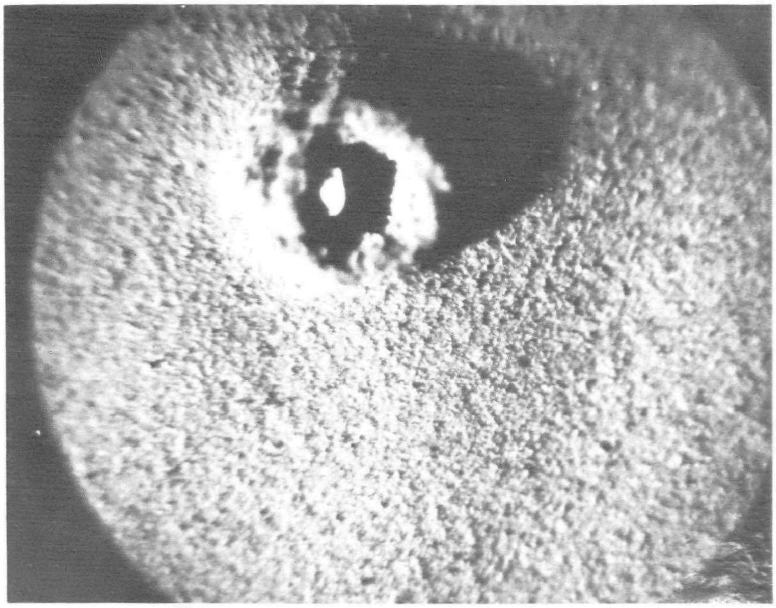
PINHOLE LEAKS AND FILTER EFFLUENTS

It was pointed out that a disproportionately large gas flow passes through the pinholes because of the latter's minimal resistance to gas flow. Detailed measurements showed that the mass of dust conveyed through the pinholes was nearly proportional to the leak flow.[3] This means that few particles >15 μm are separated from the aerosol as it converges to accelerate through a pinhole. On the other hand, the undisturbed dust cake is nearly impenetrable due to its high efficiency sieving action. *Thus, the size properties of the up- and downstream particles are essentially the same because 95 to 99 percent of the effluent is composed of the unaltered upstream aerosol.* As indicated previously, some particles (~5 to 10 percent by weight) are inertially scavenged from the pinhole flow as may be inferred from the "anthill", Figures 3a, surrounding the pinhole. Conversely, comparative condensation nuclei counts showed no separation of nuclei class particles (0.0025 to 0.5 μm) in passing through the pores. As a corollary, tests indicated that effluent nuclei concentrations were proportional to the total effluent mass concentration.[3]

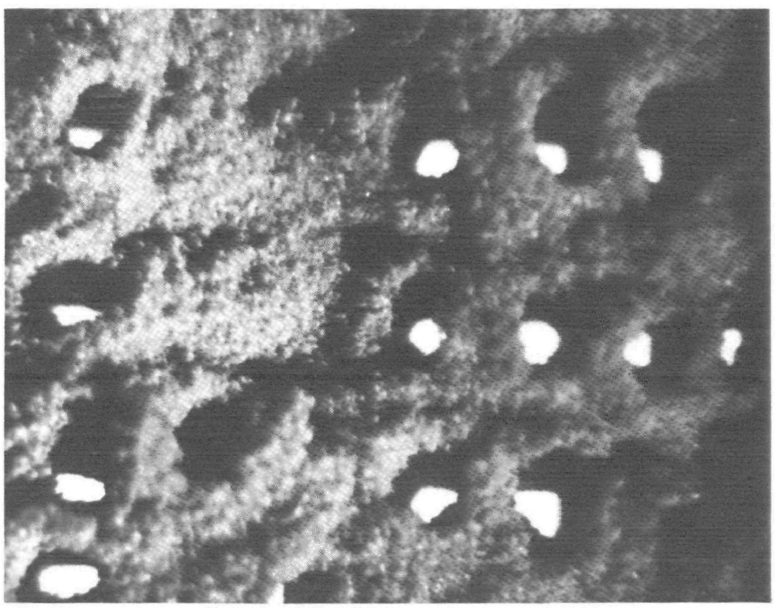
The significance of the above findings with respect to coal fly ash-woven glass fabric systems is that inlet and outlet mass concentration measurements coupled with effluent size determinations are usually sufficient to describe filter system performance. The observed differences between up- and downstream size properties often result from particle losses between the upstream sampling point and the filter and/or sampling errors. *For such systems, computed fractional size efficiencies usualy depict erroneous statistics relative to true filter behavior.*

EFFECT OF FACE VELOCITY ON COAL FLY ASH FILTRATION WITH GLASS FABRICS

Operation of fabric filters at high air-to-cloth ratios reduces space requirements and equipment capital costs. However, increased velocity also increases pressure loss and cleaning frequency which will eventually override the advantage of reduced equipment and space costs.[2] Less well understood is the relationship between face velocity and outlet concentration. This discussion focuses on glass twill weaves and their nonmineral counterparts, in which the warp multifilament yarns provide the strength and the bulked or staple fill yarns provide the actual collection capability. Ordinary wool and synthetic fiber felts, >380 g/m^2, which are used at high face velocities (~3.1m/min) are not the subject of this review. Given a typical fabric, some variability in pore size and intrapore fiber



(a). Pinhole leak, filtration surface, showing characteristic mound, substage lighting (20X magnification).



(b). Massive pinhole leakage with monofilament screen - without loose fibers.

Figure 3. Variations in pinhole leaks due to fiber presence and pore size.

dispersion is expected. At moderate velocities (0.6 to 0.9 m/min), maximum unblocked pore areas seldom exceed 10^{-4} percent of the total face area so that collection efficiencies fall in the 99.9 percent range.[3] However, this pattern may change radically when the air/cloth ratio is increased.

Because pinhole flow at a fixed filter resistance varies directly with pinhole area, it is essential that pore bridging be completed as soon as possible. With typical inlet loadings of ~2.3 to 7.0 g/m^3, nearly complete bridging takes place within a few minutes leaving only the larger pores to be closed. The extent to which the remaining pores become blocked is velocity dependent. *At higher velocities, an equilibrium may develop between the dust deposition and reentrainment rates such that certain larger pores are never blocked, Figure 3.* The effect of velocity (V) and fabric loading (W) on outlet concentration, C_o, is indicated in Figure 4.

Outlet concentrations decrease rapidly during the early loading phase, ~ minutes, followed by an asymptotic decline to a lower limit that ranges from 5×10^{-4} g/m^3 at a face velocity of 0.39 m/min to 2×10^{-1} g/m^3 at 3.35 m/min. Thus, there is a 400 fold increase in *minimum* concentration and a 25 times increase in *average* outlet concentration as a result of the velocity increase.[3] *These measurements indicate that emission levels may determine the maximum air-to-cloth ratios.*

PREDICTING SPECIFIC RESISTANCE COEFFICIENT, K_2

The permeability of a dust layer, usually expressed by the specific resistance coefficient, K_2, bears the same importance to filtration as does dust electrical resistivity, Ω, to electrostatic precipitation. In filtration, high K_2 values mean high dust cake resistance and thus increased fan power and more frequent fabric cleaning. High electrical resistivities without compensating measures can seriously reduce particle collection. The successful modeling of fabric filtration and electrostatic precipitation requires that both dust properties, K_2 and Ω, be defined accurately.

Presently, it is difficult to predict the K_2 value despite an extensive literature on the subject.[2] Problems arise because most theories derive from overly simplified geometric concepts and because the key variables are difficult to measure accurately. *Therefore, K_2 should be measured directly to avoid serious estimating errors.*[3]

However, because of the unexplicably broad scatter in reported K_2 values,[2] recent data were analyzed to explain inconsistencies. A true K_2 value must be based on the ratio of the increase in filter drag, ΔS, when the dust deposit and face velocity are uniform over the filter surface, $K_2 = \Delta S/\Delta W$. *Most field measurements do not permit the direct computation of true K_2 values because fabric loadings are not uniformly distributed on individual bags nor in collector compartments.* The problem is illustrated in Figure 5 in which typical drag versus *average* loading curves are shown for completely and partially cleaned fabrics. Curve 1 provides the only true estimate for K_2. The shapes for Curves 2 through 4 reflect various degrees of flow apportionment between cleaned and uncleaned surfaces that depend upon their respective initial resistances. Only when the filtration is performed over lengthy periods without cleaning will such curves converge to the same and correct slope for the K_2 value. In many commercial applications, the intervals between cleaning are too brief for a uniform dust deposit to develop. Additionally, there is seldom complete information on the size properties of the particles in the dust cake per se.

Because recent tests provided the required data, the Kozeny-Carmen relationship was used to predict K_2 values for comparison with actual measurements.[2,3] The variables requiring definition were gas viscosity, μ; *the specific surface parameter for the particles in the dust cake, S_o*; the discrete particle density, ρ_p and the dust cake porosity, ε. The Term S_o derives from the mass size distribution obtained by cascade impactor measurements; ρ_p, by pycnometer measurement; and ε from discrete particle density, ρ_p, and the bulk density $\bar{\rho}$ of the dust, the latter determined by light shaking of an open container of the dust.

For several dust and fabric combinations (fly ash, granite, and talc with woven glass and

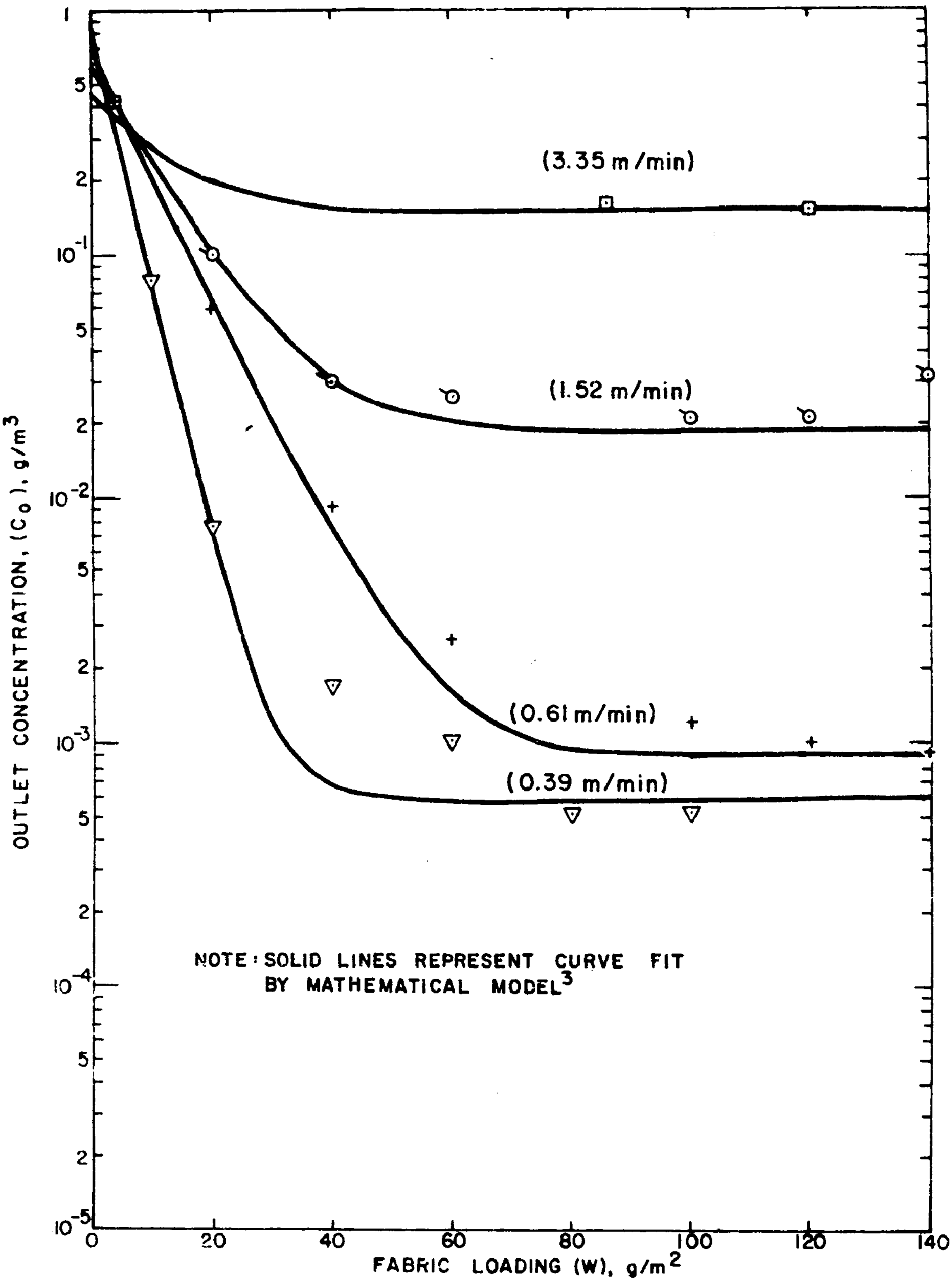


Figure 4. Effect of fabric loading and face velocity on outlet concentrations. Bench tests with coal fly ash and woven glass fabrics.

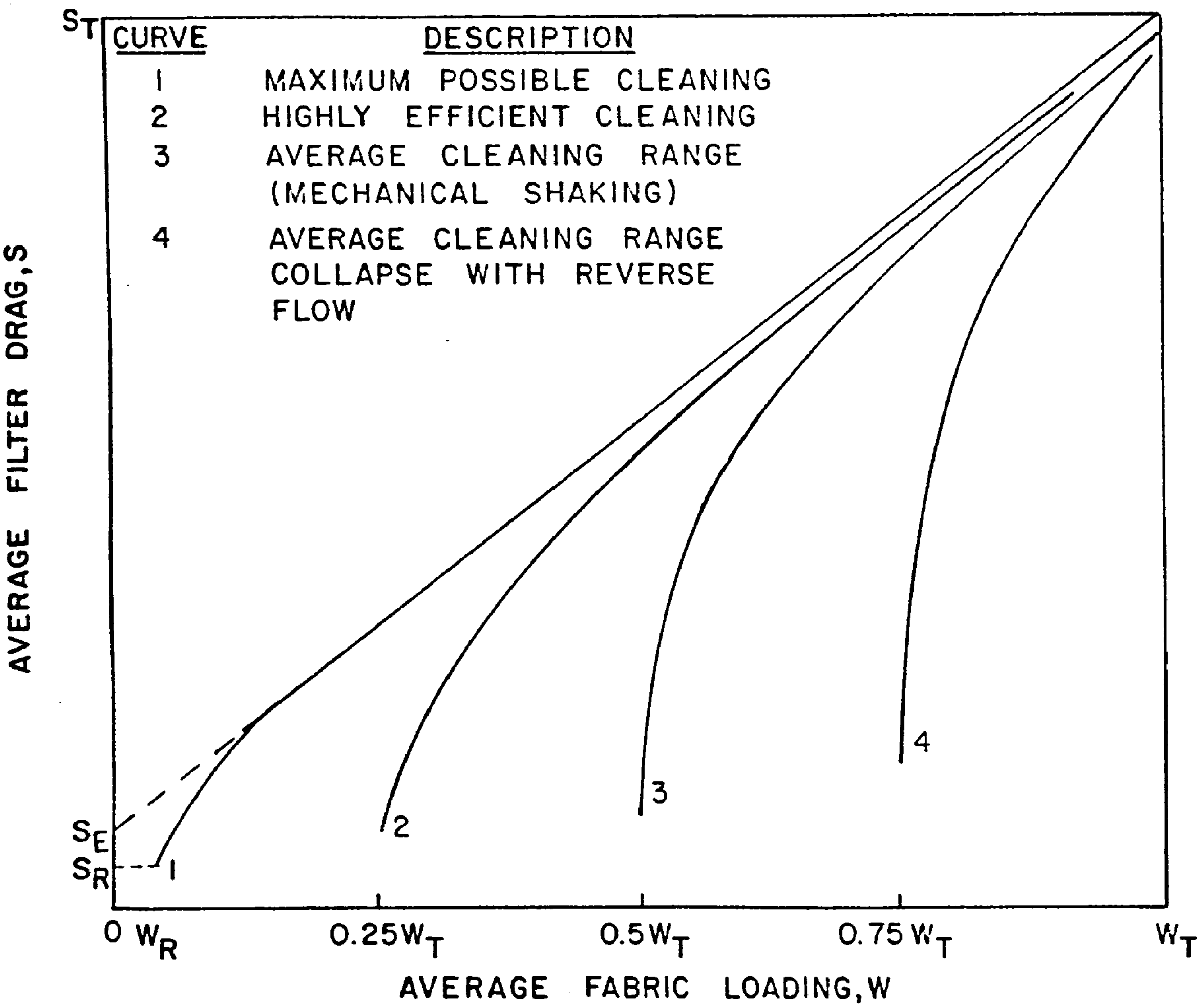


Figure 5. Typical drag versus fabric loading curves for various levels of partial cleaning

napped, sateen weave cotton) the above input parameters (in conjunction with a modified Kozeny-Carman constant of 2.5 instead of 5.0) gave fair predictions of K_2, ±50 percent of measured values.[3] Although the above accuracy is hardly sufficient for design purposes, it betters the 10-fold ranges often found in the literature.[2] Aside from uncertainties in size measurements, *it is important to note that small, ~10 percent, errors in estimating porosity and particle density can lead to 50 percent errors in K_2.*[2,3]

Gas velocity was shown to exert a significant effect on K_2 as reported by previous investigators.[2] For fly ash/glass fabric combinations, K_2 was observed to increase as the square root of the face velocity over the range 1.3 to 3.5 m/min.[3] This behavior is attributed to the fact that increased particle momentum at higher velocities creates a less porous cake. One must differentiate between this effect and that of gradual cake and/or fabric compression that occurs with dusts that deposit initially as highly porous structures.

FABRIC FILTER CLEANING - DUST DISLODGING FORCES

Fabric filtration is effective only when the filter can be cleaned periodically and economically without impairing collection efficiency or disturbing the system gas flow. Although fabric filters have been used for many years, the cleaning process has only recently been examined quantitatively.[7] Highlights of recent studies on filter cleaning by (a) mechanical shaking, (b) reverse flow or (c) combinations of (a) and (b) are discussed below.

In a simple shaking system, the oscillation of the shaker arm alternately accelerates and decelerates the dust laden bag surfaces. The resulting tensile and/or shearing forces exerted at the fabric/dust layer interface, if greater than local adhesive forces, will remove slabs or flakes of dust from the fabric as shown in Figure 6. A fluorescent tube within the bag reveals clearly the dust dislodgement sites.

The separating force (assuming that tensile and shear forces are roughly equivalent) can be estimated from the dust loading, W, and the average acceleration $\bar{a}$ imparted to the dust laden fabric.[3] The acceleration is computed from shaker arm amplitude (half-stroke) and shaking frequency. *Field and laboratory tests have indicated that average acceleration must be at least 3 g's to impart* the shaking motion over the entire bag.[7] Low frequencies, <4 cps, and small amplitudes, <1 cm, generate acceleration forces appreciably less than that attainable in a gravity field.[7]

Bag collapse accompanied by a clean, reverse air flow (usually less than the face velocity) is a preferred method of cleaning glass fabrics because it avoids the stresses caused by mechanical shaking. Here the cleaning principle is the same as that for shaking except that the dislodging force is now defined by the product $W \cdot g$ rather than $W \cdot \bar{a}$. *The flexing rate and the bag curvature after collapse, which may also play important roles in dust dislodgement, require further study.*

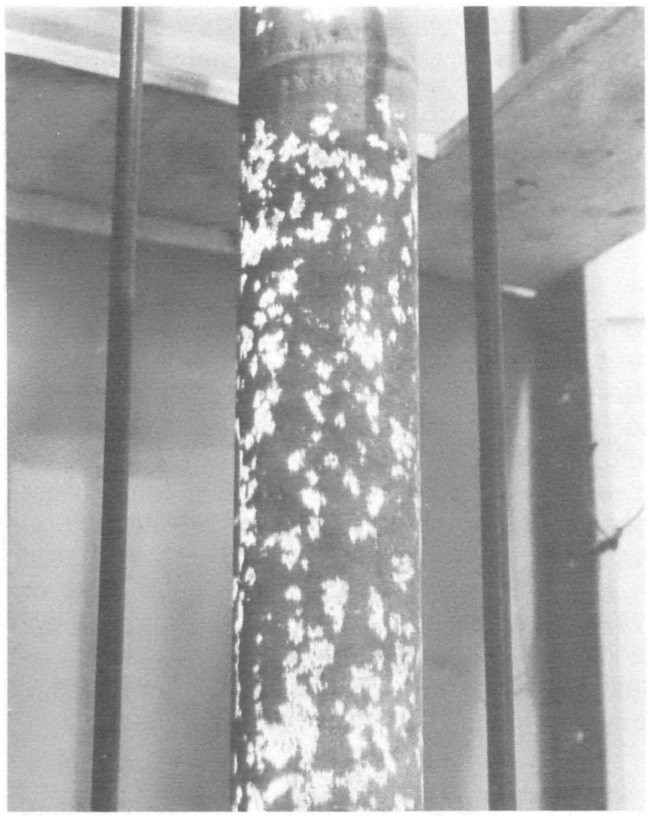


Figure 6. Cleaned *bag with illumination from inside by fluorescent tube.*

FABRIC FILTER CLEANING - RESIDUAL DUST AND ADHESIVE FORCES

Although dust removal forces may be approximated for shaking or reverse flow systems, determination of the actual amount and location of the separated dust requires information on dust/fabric adhesion. Rough estimates of adhesion have been proposed for selected fly ashes and twill weave glass and sateen weave cotton fabrics.[2,3] These measurements, however, provide insights as to (a) how dust separates from a fabric and (b) how adhesive forces are probably distributed.

First, because fly ash usually forms low porosity (<0.7) deposits, the *cohesive forces within the dust cake because of multiple particle contacts far exceed the adhesive forces between widely spaced yarns and the interface particles.* Therefore, dust separates at the dust/fabric interface where the bonds are weakest. The cleaned region beneath the dislodged dust always displays the same residual dust holding, W_R, and the same cleaned cloth drag, S_R. Residual dust on glass fabrics averages about 50 g/m^2, whereas cotton sateen retains more, 75 g/m^2, because of increased fiber cover. In both cases, the residual dust is found mainly within the bulked, loosened fibers and rarely on the smooth surfaces of multifilament yarns.

The unique properties of the cleaned fabric, Figure 6, allow one to determine the gas flow distribution with respect to location and time once a filter compartment is returned to service after cleaning.[3] It is only necessary that the fraction of cleaned bag area (a_c) be determined. An empirical approach has been proposed which allows a_c to be estimated from the fabric dust loading before cleaning, W_P, or the separation force, F_S, when the dust loading is acted upon by gravity or shaking acceleration; i.e., Wg or $W\bar{a}$.[3] Since the adhesive force, F_A, is just exceeded by the separating force at the instant of dust dislodgement, Figure 7 also furnishes a rough measure of adhesive force.

Despite the data scatter, the description of dust separating forces in terms of the products, $W \cdot g$ or $W \cdot a$ appears as a rational means for estimating the amount of cleaning accomplished by reverse flow and mechanical shaking. The principal limitation to this approach is that each dust/fabric combination possesses its unique adhesion properties as suggested by glass and cotton fabric data, Figure 7. Thus, until an improved theory is developed, it will be necessary to determine a_c by special laboratory studies or by detailed analyses of field measurements.

PREDICTING FILTER PERFORMANCE

The adaptability of glass fabrics to fly ash filtration suggests their use where low sulfur coal and/or high ash resistivity preclude efficient electrostatic precipitation. Until recently, however, there were no means short of pilot plant testing for predicting operating and performance parameters for a specified dust/fabric application in a prototype system.

Despite many past attempts to develop filtration models,[2,3] failure to define the true nature of a cleaned fabric surface usually led to poor results when such models were applied to nonreplicate systems. Recent studies have indicated that many conventional filtration processes can be modeled if the following factors are definable:

- The amount of dust on the filter before cleaning, W_P, and its terminal drag, S_T.
- The fraction of *cleaned* area, a_c, exposed by the cleaning action and its characteristic residual drag, S_R, and fabric loading, W_R.
- The K_2 value for the dust (preferably determined by experiment) and the relationship between K_2 and the filtration velocity, V.
- The relationship between the method and intensity of cleaning and the fraction of cleaned area produced.
- The relationship between outlet concentration and face velocity, fabric loading, inlet concentration, and specific dust/fabric combination.

Integration of the above data into an iterative calculating procedure for sequentially-cleaned, multicompartmented baghouses describe closely the performance of real filter systems.[3] In view of the numerous mathematical functions constituting the model, the reader is referred to the original report for details on its design and applications.[3] It is emphasized, however, that the basic building blocks for the predictive equations are the well accepted filter drag versus fabric loading relationships. What the model does is to integrate the performances of individual filter elements operating in parallel where resistance, velocity, dust penetration and K_2 vary with respect to time and location. Based upon validation tests using field data for the Sunbury and Nucla operations, its use as a diagnostic tool showed very encouraging results, Table 1.[3]

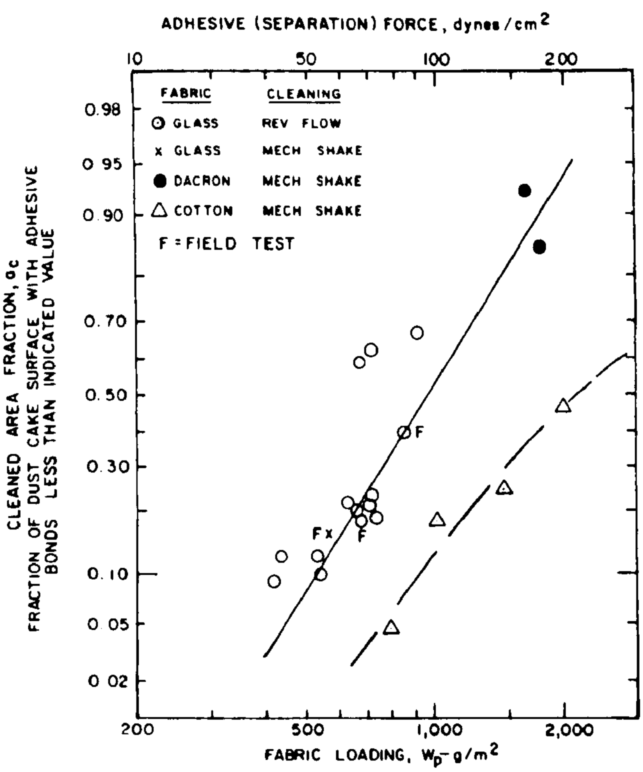


Figure 7. Fabric cleaning and distribution of adhesive (separation) forces versus fabric loading and adhesive (separating) force - Coal fly ash.

Table 1. MEASURED AND PREDICTED PERFORMANCE FOR WOVEN GLASS BAGS WITH COAL FLY ASH

	Percent penetration	
	Measured*	Predicted*
Nucla, Colorado	0.21	0.19 (1.52)†
Sunbury, Pennsylvania	0.15	0.20
	Resistance-kPA	
	Measured	Predicted
Nucla, Colorado		
Average, cleaning and filtering	1.03	0.97
During cleaning only	1.7	1.52
Maximum just before cleaning	1.16	1.16
Minimum just after cleaning	0.85	0.72
Sunbury, Pennsylvania		
Average, cleaning and filtering	0.64	0.62
During cleaning only	0.71	0.66
Maximum just before cleaning	0.71	0.66
Minimum just after cleaning	0.56	0.57

*Averaged over cleaning and filtering cycles.
†During cleaning cycle only.

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16. ABSTRACT The report highlights significant developments in fabric filtration technology. It reviews results of several field and laboratory studies performed over the last 10 years, by or under the sponsorship of the EPA, so that the reader may be better able to assess filtration equipment capabilities and limitations. A background of fabric filter design and operational concepts is followed by a sampling of actual field performance with various coal fly ash aerosols and a description of an operational mobile pilot filter system that is used to facilitate the selection of operating parameters, fabric type, and method of fabric cleaning. Fabric weave and constituents are discussed with respect to their bearing on working temperatures, method of cleaning, fabric life, pressure loss, and dust retention. Attention is also called to the impact of pinhole or pore leakage on collection efficiency and effluent size properties. The pros and cons of increasing air-to-cloth ratio (face velocities) to reduce fabric and other capital costs are compared with attendant disadvantages of increased power needs and higher emission rates. Pilot and bench scale tests show that effluent concentrations increase very rapidly with face velocity. Recently developed modeling concepts that provide realistic predictions of glass fiber performance with coal fly ash are reviewed.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Coal	Pollution Control	13B	21D
Dust Control	Glass Fibers	Stationary Sources		11B
Gas Filters		Particulate	13K	
Fabrics		Fabric Filters	11E	
Aerosols			07D	
Fly Ash			21B	

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